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Langmuir probe study of the floating potential fluctuations in the dc cylindrical magnetron discharge

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The plasma potential fluctuations in the cylindrical magnetron discharge were measured using the Langmuir probes. The power density spectra were calculated in the range of magnetic fields 10 to 40 mT, pressures 1.5 to 7 Pa and discharge currents 100 and 200 mA.

1. Introduction

The cylindrical magnetrons are nowadays widely used as technological systems e.g. for creating thin films of superconductive or special magnetic properties. In the cylindrical magnetron the symmetry and homogeneity of the magnetic field simplifies both the theoretical and experimental investigations. In our previous experimental studies we already reported the presence of fluctuations of the plasma potential [1]. Fluctuations manifest as the unwanted noise added to the Langmuir probe voltage and in the increased noise of the measured current. The amplitude of the fluctuations significantly increases when the magnetic field increases above the value of approximately 20 mT. In this contribution the more detailed experimental study of the plasma potential fluctuations in our cylindrical magnetron system is presented.

2. Experimental system

Our construction is in more detail described in [2]. Briefly, the cylindrical magnetron is in the so-called post configuration and consists of cylindrical cathode mounted co-axially inside of the anode. The discharge volume is axially limited by means of two disc-shaped limiters, which are connected to the cathode potential. In our device the diameters of the cathode and anode are 18 mm and 60 mm respectively. The length of the discharge volume is 300 mm. The homogeneous magnetic field is created by six coils and is parallel with the common axis of the system. To prevent overheating both the coils and the cathode, they are water-cooled.

The system is constructed as high vacuum. The pumping unit consists of the combination of the turbomolecular and rotary pumps. The ultimate pressure is in the order of 10^{-3} Pa. During the experiments with the magnetron discharge the argon working gas slowly flows through the system at typical flow rate below 1 sccm (standard cubic centimetre per minute). The flow is adjusted by means of the MKS flow controller with the pressure signal at the reference input - thus keeping the constant pressure in the discharge chamber.

The system is equipped with 5 ports for inserting the Langmuir probes. Ports are distributed at the distances of 60 mm from each other along the discharge vessel. The probes could be inserted radially into the system. For the purpose of measuring the frequency vs. wave number spectra we used a twin Langmuir probe with two tips separated by the distance 1.7 mm. The tungsten cylindrical probes had diameter 47 μm and length 2.5 mm. The probe tips were parallel and laid in the plane that was perpendicular to the magnetic field lines.

3. Estimation of the power spectra

The Langmuir probes were used without the bias voltage. That is, their floating potential signal was sampled using the digital oscilloscope (Tektronix TDS 520A) and samples h_n were transferred to the computer via the GPIB interface

$$h_n^{(i)} = h^{(i)}(n \cdot \Delta t), \qquad (1)$$

where $h^{(i)}(t)$ is the probe voltage with respect to the anode, Δt is the sampling interval and integer n ranges from 0 to the number of samples N-1. Superscript (i) denotes number of realisation (measurement). Then the discrete Fourier transform of the sampled data was calculated by means of the FFT (j represents imaginary unit):

$$H_m^{(i)} = \sum_{n=0}^{N-1} h_n^{(i)} \exp\frac{-2\pi \mathrm{j} mn}{N}. \qquad (2)$$

The estimate of the Fourier transform of the voltage $h^{(i)}(t)$ at the discrete frequencies $m\Delta f$ is given by

$$H^{(i)}(m \cdot \Delta f) = \Delta t \cdot H_m^{(i)}, \qquad (3)$$

where $\Delta f = 1/(N\Delta t)$. The estimate of the power spectral density is then

$$S(f) = \left\langle \frac{1}{N\Delta t} \left| H^{(i)}(f) \right|^2 \right\rangle. \qquad (4)$$

Here the angle brackets represent the statistical ensemble average over large number of realisations (range of (i) was typically 100).

4. Frequency vs. wave number spectra

We attempted to analyze the wave behavior of the potential fluctuations of the magnetron discharge. For that purpose the spectra derived from the fluctuations measured simultaneously from two Langmuir probes were evaluated according to the method developed in

[3]. At first the wave number was expressed for each frequency from the phase shift between the signals at the two probes (denoted by subscripts 1 and 2) and the known distance Δx between the probes:

$$k^{(i)}(f)=\frac{\arg H_2^{(i)}(f)-\arg H_1^{(i)}(f)}{\Delta x} \qquad (5)$$

Using the wave number and the average power density at the two probes $[S_1^{(i)}(f)+S_2^{(i)}(f)]/2$ the histogram $S(f,k)$ can be built by the ensemble averaging the same way as in [3]. The range of (i) was also typically 100.

It is interesting to note that this method can be looked at as the frequency domain version of the classic method of so-called z-t diagrams. This analog method was used for visualization of ionization waves in glow discharges in time domain, see e.g. [4,5].

5. Results

Figure 1 shows the dependence of the measured power density spectrum on the magnetic field at the pressure 3 Pa and the discharge current 200 mA. In the range up to several kHz the increase of the fluctuations amplitude with the increasing magnetic field is seen. The peaks on the curve taken at the magnetic field 20 mT are probably connected with the noise of the discharge power supply rather than with special fluctuation modes.

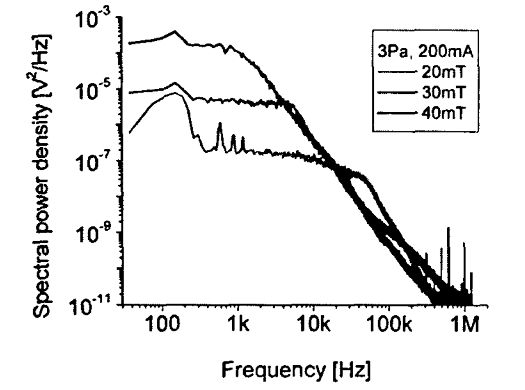

Figure 1. Example of power signal density spectrum with the magnetic field strength as parameter.

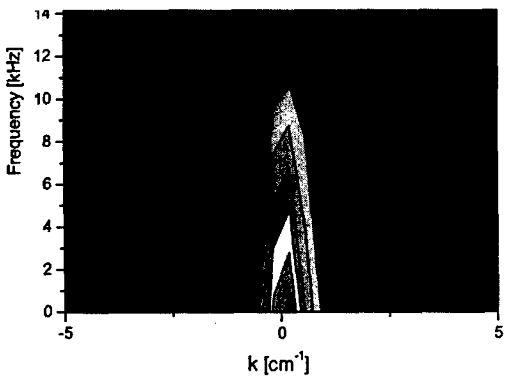

Figure 2. $S(k,f)$ histogram at 30 mT, 1.5 Pa and 200 mA. The distance between the two Langmuir probes was 1.7 mm.

The spectra derived from the fluctuations measured simultaneously from two Langmuir probes were also evaluated. Figure 2 shows the typical frequency vs. wave number histogram. It is seen from the figure that until approximately 15 kHz the phase shift between the fluctuations measured at the two probes is negligible, i.e. that the fluctuations at the positions of the two probes are well correlated.

6. Discussion

In the work [3] several fluctuation modes were observed in a planar dc magnetron device. The modes were present only when the discharge power and the neutral gas pressure were above a certain threshold. Their frequency spacing decreased when the neutral gas pressure was raised. Consequently, increasing of the pressure lead to a more turbulent state.

We investigated the fluctuations in the described cylindrical magnetron system in the range of magnetic fields 10 to 40 mT, for pressures from 1.5 to 7 Pa and at discharge currents 100 and 200 mA. Within this range of parameters we always found only one fluctuation mode, similar to that in figure 2. In other words the fluctuation in our system are the "synchronous oscillations" rather that travelling waves detected in the planar magnetron configuration. In the future we plan to refine the measurements by using the A/D card with better bit resolution.

7. Acknowledgments

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